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A System Dynamics Modeling Approach for Corporate Profit With Product Reliability

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Abstract
This paper proposes to develop a system dynamics model to study the impact on corporate profit with product reliability. In previous studies, most results suggest product reliability has complex impact on corporate profit. However, the quantitative study is far from adequacy. The study uses system dynamics theory to simulate corporate profit and analysis the influence of product reliability on corporate profit. It provides a way to quantitative analyze the corporate profit trends along with the change of product reliability.

Key words: System dynamics; Product reliability; Corporate profits

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INTRODUCTION
Many corporations pay attention to their product reliability in modern market system. More and more research results suggest that product reliability has closely connection with cost, which influences corporate profit directly or indirectly. Kleyner and Sandborn (2008) tried to minimize life cycle cost by managing product reliability. Kimura, Toyota, and Yamada (1999) discussed software release problems considering with warranty cost and reliability requirement. Zhang (2001) and Shi (2004) established reliability and cost models in different ways (Zhang & Han, 2001; Shi et al., 2004). These research results provide preliminary proof for the existence of causation between product reliability and cost. And the cost is an important part of corporate profit system. So to some extent the product reliability has closely connection with profit.

Product reliability is an indicator to describe product failure. If the product reliability is too bad, product failure decreases customer satisfaction and destroys customer loyalty. The corporate may lose customers and its sales volume may decreases. In addition, product with bad reliability needs high O&S cost (operational and support cost). These all make corporations have to consider improving product reliability. But increasing product reliability needs large amount of cost and resources. In order to increase product reliability, corporation needs to introduce advanced equipment, advanced materials, advanced technology and high quality technical personnel. It will increase cost of corporation. While on the other hand, product with good reliability will leave the customers a good impression. It will increase customer satisfaction and customer loyalty. The sales volume and price will increase. As product reliability increased, the rework cost and operational and support cost will decrease. In one word, increasing product reliability has both positive impact and negative impact on corporate profits. Therefore, the managers need to know the final impact of increasing product reliability on corporate profits. It helps managers to decide whether to improve reliability or not.

This paper use system dynamics to simulate corporate profit system. It constructs a simulation model to show the relation between product reliability and corporate profit. It shows the profits trend along with product reliability change.

This paper is organized as follows. Section 2 introduces the relevant literature about this paper. Section 3 describes the details of the simulation model. Section 4 shows the results of the simulation using data from a real-life case situation, and finally Section 5 presents the conclusions.

1. LITERATURE REVIEW

There are many researches related to the relationship between reliability and cost. For instance, Kleyner and Sandborn (2008) tried to minimize life cycle cost by managing product reliability, based on a principle that product reliability has big influence on life cycle cost, which was demonstrated in Kimura, Toyota, and Yamada (1999) research of the optimal balance between minimizing the total expected software cost and satisfying a reliability requirement. Besides the discussion of balance between cost and product reliability, some quantitative models were established to show the influence of product reliability on the cost. For instance, Shi et al (2004) have proposed a model of the weapon equipment system life cycle cost and reliability according to the famous quality cost model by the American quality management expert, Dr. J. M.

The researches above have shown the influence of product reliability on cost. And the cost has a great impact on corporate profit, which was demonstrated in the researches of Sundkvist. Sundkvist, Hedman, and Almström (2012) and LÜ (2012). In other words, product reliability indirectly influences the corporate profit. As the influence is complex and uncertain, it is not possible to establish a quantitative equation of product reliability and corporate profit. In this paper, we use system dynamics to simulate corporate profit system to study the relationship between product reliability and corporate profit.

System Dynamics is a powerful tool to study complex dynamic system. As corporate profit system is complex and dynamic because of its uncertain factors, this paper use system dynamics to simulate corporate profit system to show the relation between product reliability and corporate profits. Since 1956, Forrestor proposed system dynamics to study dynamic system (Luo, 2009). Then system dynamics has been widely used in various fields. In economics, it is mostly used in research of demand and supply problems. Ashayeri and Lemmes (2006) used system dynamics to construct a simulation model to show the financial consequences of an improved demand planning reliability in the supply chain. It helps managers to make decision based on knowing how improvements in their demand reliability will impact the corporate bottom-line, which is the output of the simulation model. Smith and Ackere (2002) used system dynamics to study in equilibrium between supply and demand. They showed the approaching to equilibrium by system dynamics simulation. Campuzanoa, Mulab, and Peidro (2010) used an integration method of fuzzy estimations and system dynamics to simulate a two-stage, single-item, multi-period chain. The simulation model used fuzzy numbers to represent demand and orders in supply chains. The results showed that a system dynamics model with fuzzy numbers can effectively reduce the bullwhip effect in supply chain. There are also a few researches about using system dynamics to study corporate profits. Luo (2009) used system dynamics to simulate the profit system of the main manufactures in aviation weapons and equipment supply chain. The results demonstrated the impact of the procurement and support policies by department of defense and military on the main corporate profits. Through simulation and analysis, he proposed some advice for the managers to improve the overall performance of the supply chain. Ding (2009) constructed a simulation model of cost-benefit relationship of the power plant profits by system dynamics. The model can forecast the corporate profit trends and help managers make decisions. Liu et al. (2010) used system dynamics to construct a model for corporate profit system. And combined with the example, they analyzed the corporate profit trends and proposed advices for managers.

However, the models above didn't combine product reliability with corporate profit. Based on these researches, this paper introduces product reliability into corporate profit system, demonstrates the correlation between product reliability and corporate profits and provides a reference for managers.

2. SYSTEM DYNAMICS MODEL

In this section, the system dynamics model will be established by two steps. The first step, a causal relationship assumption is made combined with the practical situation of corporations through researching. Then the flow diagram is established according to system dynamics theory based on quantitative analysis of the causal relationship.

2.1 Causal Relationship Assumption

The relation between product reliability and corporate profits is complex and dynamic. It is assumed here that the corporate profits are totally from the products. Product with high failure causes unsatisfactory of customers so that the sales volume will be reduced. In other words, product reliability influences products sales volume, and then influences sales revenue and corporate profits. Improving product reliability needs large amounts of resources, like qualified workers, high-quality materials and advanced equipment. It means more R&D investments. On the other hand, product with good reliability needs less O&S cost. That is to say, product reliability influences corporate cost, and then influences corporate profits.

Based on the above causal relationship, the main factors in the model include:

i. Product reliability, which has both positive and negative effects on corporate profits.

ii. R&D investment, which depends on corporate profits and be used to improve product reliability.

iii. O&S cost, which is the cost to ensure the use of product after-sale.

iv. Sales revenue, which is increased along with product reliability.

v. Cost, which includes all the costs in the manufacturing production process

vi. Profit, which means corporate profits, and the profit trends is forecasted by the model.

The relationship between the main factors is shown in Figure 1.

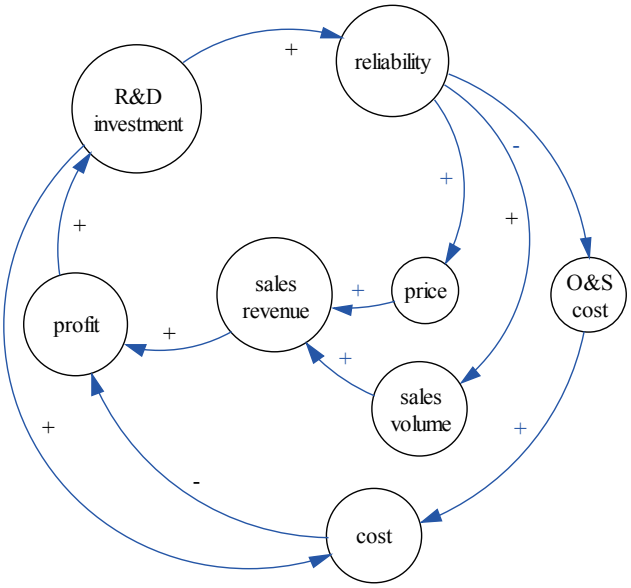

Figure 1
Causal Relationship Assumption in Corporate Profit System

There are four causality relation feedback loops in the causal relationship assumption above, shown as follows:

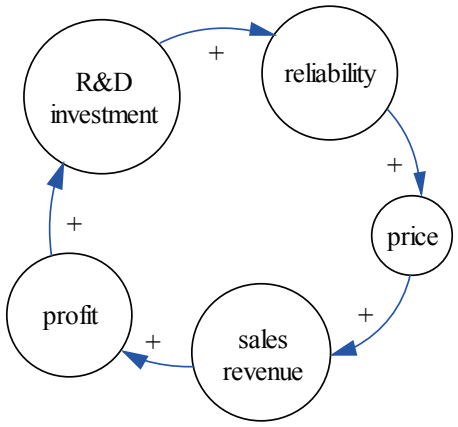

Figure 2
Causality Relation Feedback Loop 1

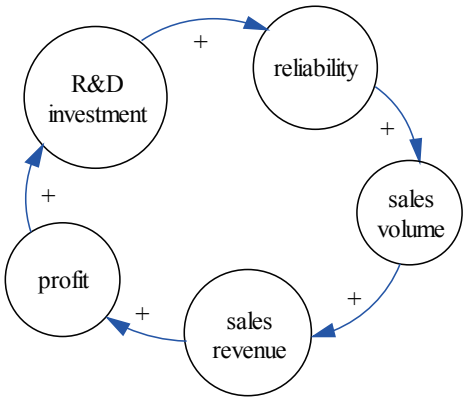

Figure 3
Causality Relation Feedback Loop 2

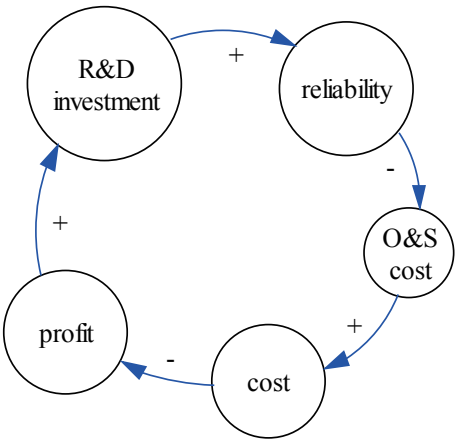

Figure 4
Causality Relation Feedback Loop 3

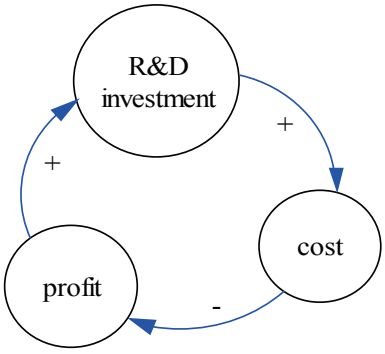

Figure 5
Causality Relation Feedback Loop 4

Three of the causality relation feedback loops are positive feedback loop. The remaining one is negative feedback loop.

2.2 Flow Diagrams Analysis

Based on the causal relationship assumption above and analysis of the main factors and relationship between them, the equations describing their quantitative relations are determined. Besides these variables, there are also some relevant factors should be introduced into the system dynamics model (see Figure 6).

There are three kinds of quantitative relations in the model above:

(a) Relations between stock variable and flow variable:

$$\text{profit}=P_0(\text{inital profit})+\int_{t_0}^{t}(\text{profit changed})\,dt \quad (1)$$

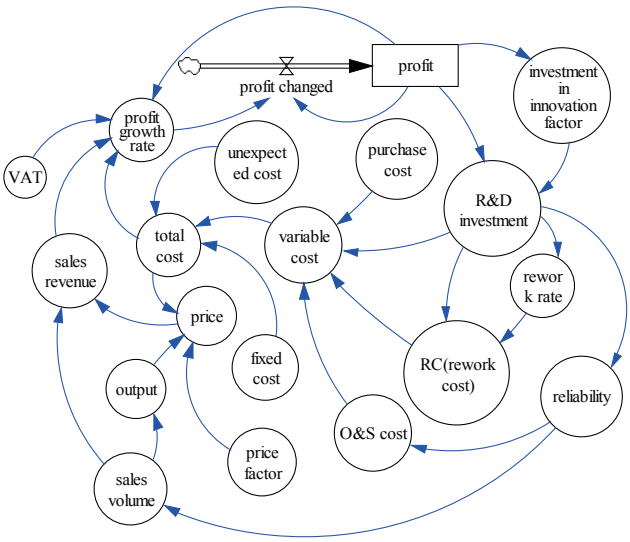

Figure 6
Simulation Model of Corporate Profit System

(b) Relations between auxiliary variables:

Reliability and R&D investment (Shi et al., 2004):

$$C_{R\&D}=C(K_1)\times\left[\tan\left(\frac{\pi}{2}\times\frac{R}{R_L}\right)\right]^{K_1} \quad (2)$$

Reliability and O&S cost (Shi et al., 2004):

$$C_{O\&S}=C(K_2)\times\left[\cot\left(\frac{\pi}{2}\times\frac{R}{R_L}\right)\right]^{K_2} \quad (3)$$

Total cost:

$$\text{Total cost=Variable cost+ Fixed cost+ Unexpected cost} \quad (4)$$

Variable cost:

$$\text{variable cost=R\&D investment+ O\&S cost+ purchase cost+ rework cost} \quad (5)$$

Price:

$$\text{price }=(\text{total cost}\div\text{output})\times(1+\text{price factor}) \quad (6)$$

(c) Table-valued function:

Table 1
Reliability and Sales Volume

R	0.6037	0.8526	0.7419	0.7969	0.8239	0.8997	0.9286
Sales	1011	1126	1368	1589	1658	1195	1053

The parameters in equation (2) and (3) are set by history data. Some variables in the model like VAT need inputting initial values. The initial values were set by the first year data we got from the real-life corporation (see Table 2). Listed above are the main equations in the model.

Table 2
Initial Values in the Model

Variables	Vat	Profit	Purchased cost	Fixed cost
Initial value	5e+005	1.5e+006	3.4e+005	1.2e+006

3. CASE STUDY AND RESULTS

In this section the results expected from the simulation model are outlined using the data from a bulldozer manufacturing enterprise. Base on the practical investigation of the manufacturing enterprise, we collected the related data for the past decade. Since there are limitations, in the model we only consider the value-added tax (VAT), not taking into account all the taxes. We assume that corporate income is entirely from the bulldozers, not involved in other business income. The main results were described as follows:

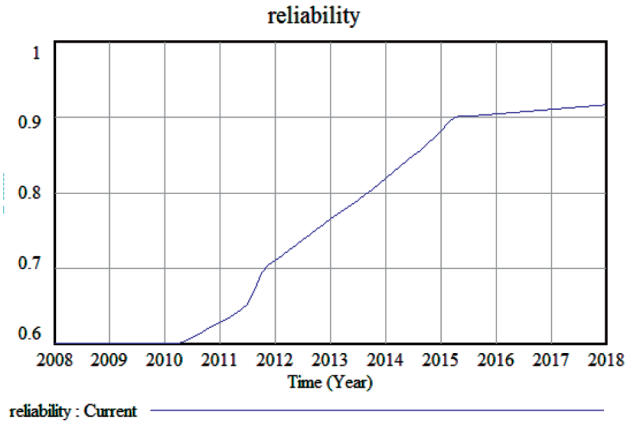

Figure 7
Simulation Results of Product Reliability

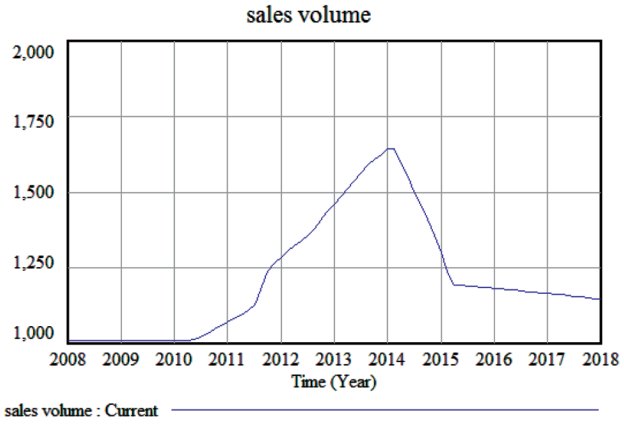

Figure 8
Simulation Results of Sales Volume

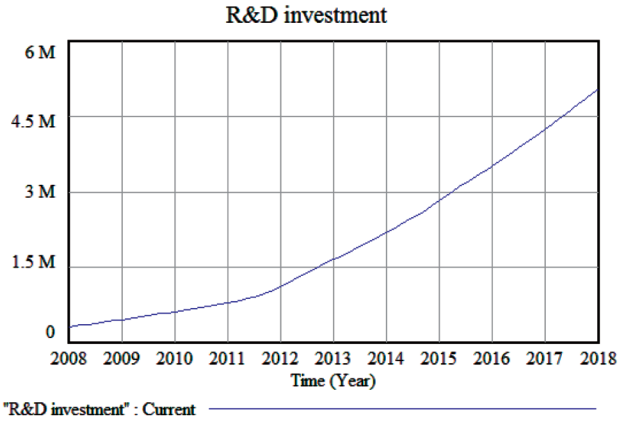

Figure 9
Simulation Results of R&D Investment

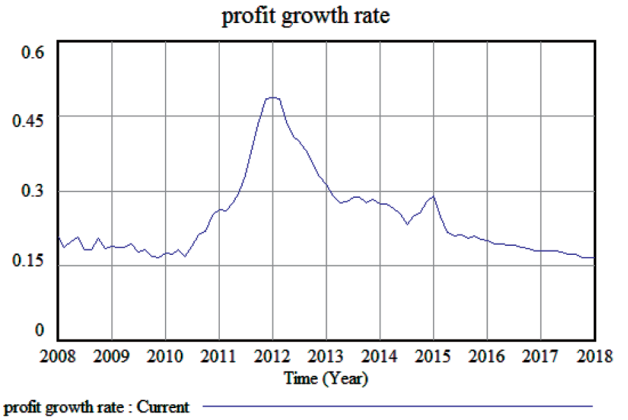

Figure 10
Prediction of the Corporate Profit Growth Rate

As shown in the simulation results above, bulldozers reliability of the first two years almost unchanged along with a low level of R&D investment. Since 2010, R&D investment has been increasing, the bulldozer reliability improved along with it until 2015. It is predicted that the bulldozer reliability will maintain the level about 0.92 (shown in Figure 7). Even to increase R&D investment cannot make the breakthrough growth in bulldozer reliability (comparison of Figure 7 and Figure 9). Due to the actual situation of bulldozer industry and technological limitations, the bulldozer reliability hardly achieves a higher level.

The simulation results of sales volume and profit growth rate show that sales volume and profit growth rate maintained a low level when the bulldozer reliability did not increase. Then as the bulldozer reliability improved, sales volume and profit growth rate started rising. Until achieving a level, sales volume and profit growth start to decline (see Figure 8 and Figure 10). In other words, there are maximums of the sales volume and profit growth during the process of bulldozer reliability increasing. After bulldozer reliability reached a certain level, further increase of the reliability will bring substantial growth of the cost, and then the price of bulldozer will increase correspond with it. The sales volume and profit will begin to decline. If the managers decide to increase investment, there would be negative growth in the corporate profits.

CONCLUSION

The product reliability takes an important role in many manufacture industries. The corporations had to improve their product reliability to meet customers' demand. On other hand, that means significant growth of the budget and resources. Then, it is required to balance the cost and profit. This paper discusses the influence of product reliability on corporate profits, and builds a system dynamics model to simulate the corporate profit system. It provides a way to quantitative analyze the corporate profit trends along with the change of product reliability. The simulation results may provide some reference for decision making.

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